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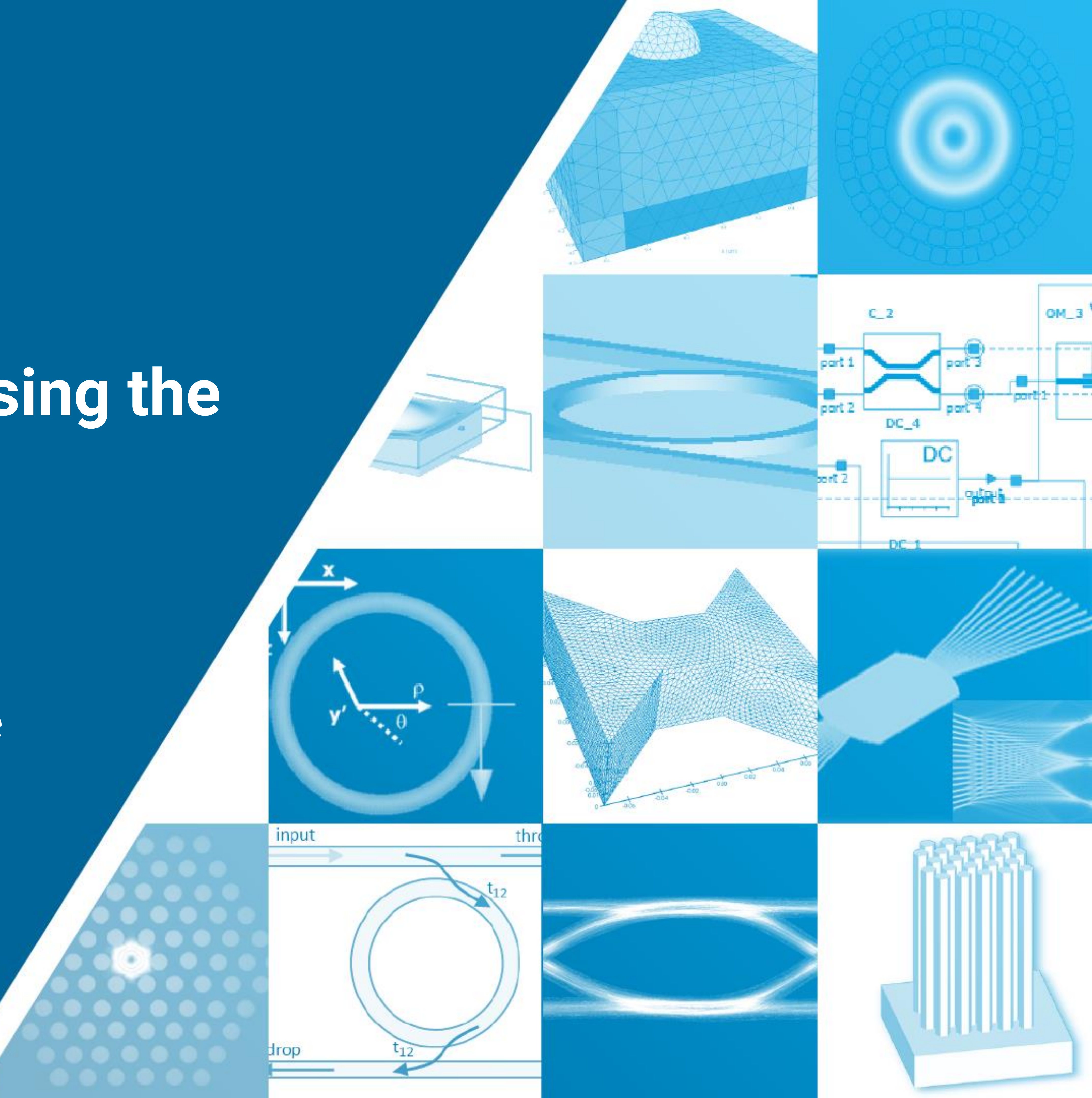
Photonic Inverse Design using the Adjoint Method

Workshop: Optimize a splitter in one hour!



Lumerical Inc.
May 2019

Inverse Design Workshop preparation

Download workshop materials at:

https://kx.lumerical.com/t/lumerical-and-siepicfab-inverse-design-workshops/34471

Ensure you download and install the latest version of FDTD Solutions from https://www.lumerical.com/downloads/customer/

Necessary if you want to perform layout of your final design for submission to SiEPIC

- Install Klayout (http://www.klayout.de/build.html)
- Install the SiEPIC Ebeam PDK by following the instructions at https://github.com/lukasc-ubc/SiEPIC_EBeam_PDK/wiki/Installation-instructions

Lumerical's Suite of Tools

DEVICE Suite
Multiphysics

FDTD Electromagnetics
MODE Waveguide Component Design
DGTD Finite Element Electromagnetics
FEEM Eigenmode Analysis
CHARGE Charge Transport
HEAT Heat Transport
STACK Optical Stack Analysis

SYSTEM Suite
System & Circuit

INTERCONNECT PIC Simulation
CML Compiler Automated CML Generation
System Element Library Extension
Laser Element Library Extension
Verilog-A Runtime API

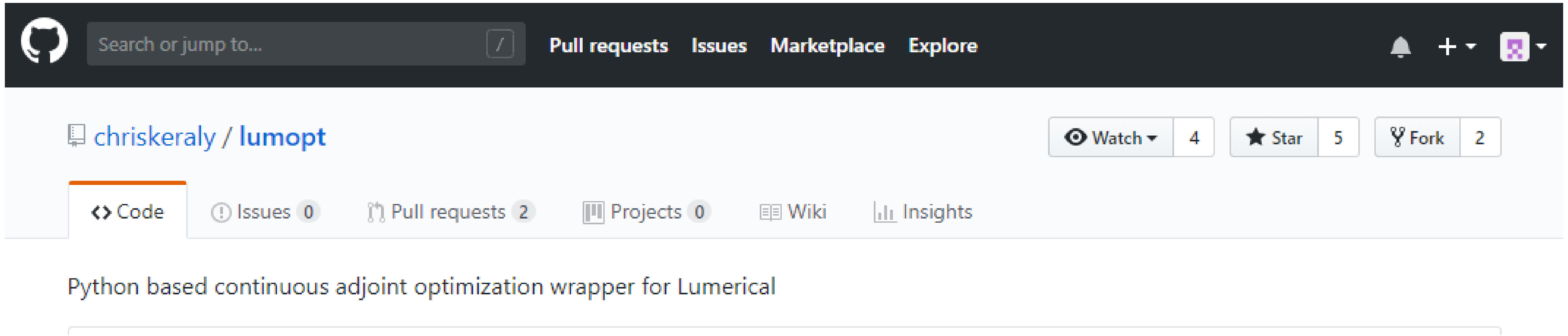
Partner Interoperability
Automation API Python Integration
Foundry Resources

INTEROPERABILITY, AUTOMATION & FOUNDRY SUPPORT
Interfaces

Lumopt: Python Based Inverse Design for Lumerical FDTD

- Lumopt: open source implementation of the adjoint method
- Collaboration with Lumerical over past year
- Targets integrated photonics
- Uses FDTD Solutions for simulation
- Uses Lumerical Automation API
- **Now included with FDTD Solutions**

https://github.com/chriskeraly/lumopt



Adjoint shape optimization applied to electromagnetic design

Christopher M. Lalau-Keraly,[1,*] Samarth Bhargava,[1] Owen D. Miller,[2] and Eli Yablonovitch[1]

[1]Department of Electrical Engineering and Computer Sciences, University of California at Berkeley, Berkeley, California 94720, USA

[2]Department of Mathematics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

[*]chrisker@eecs.berkeley.edu

Optics Express, Vol 21, Issue 18, 2013

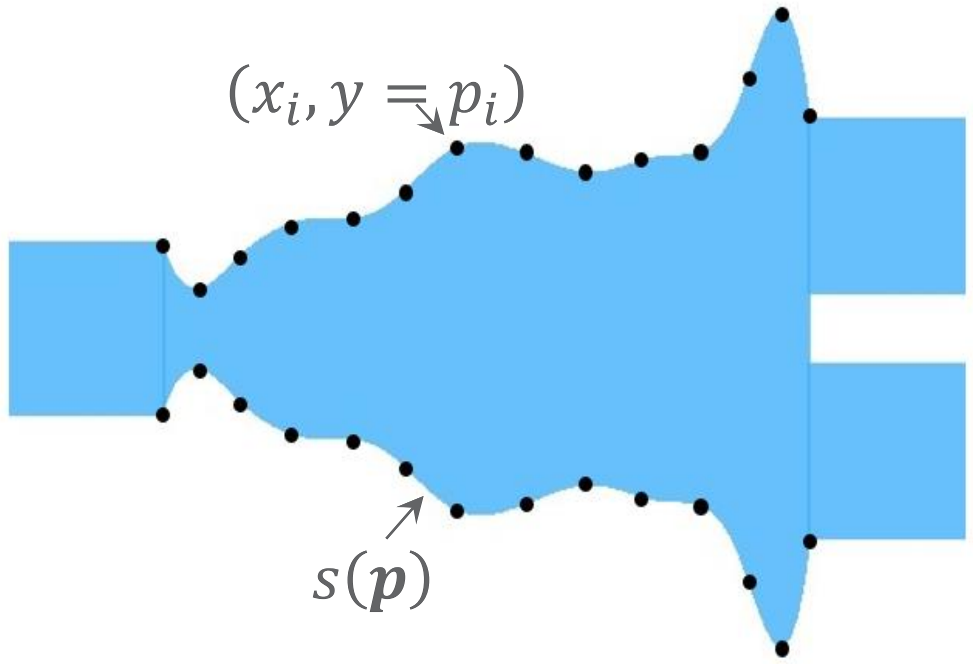
https://www.osapublishing.org/oe/abstract.cfm?uri=oe-21-18-21693

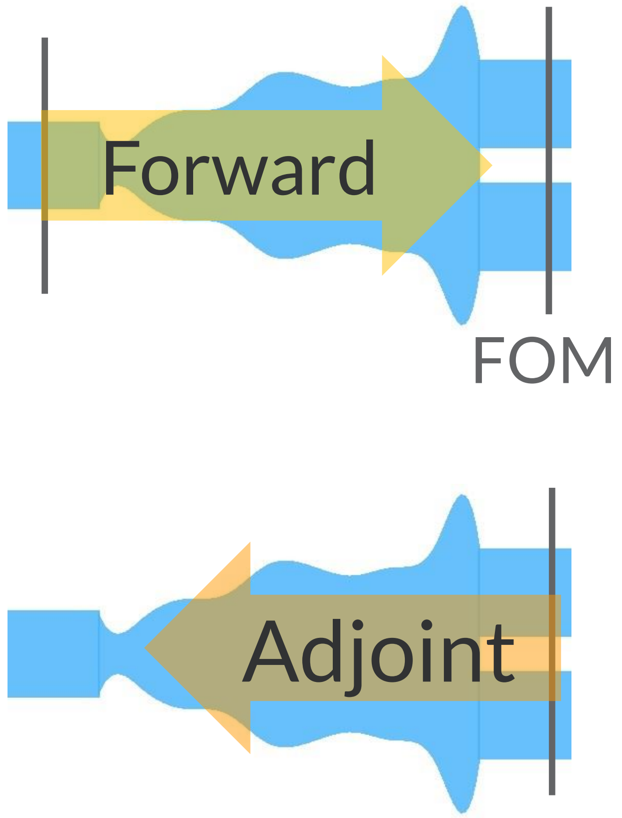
Parametric Shape based adjoint optimization

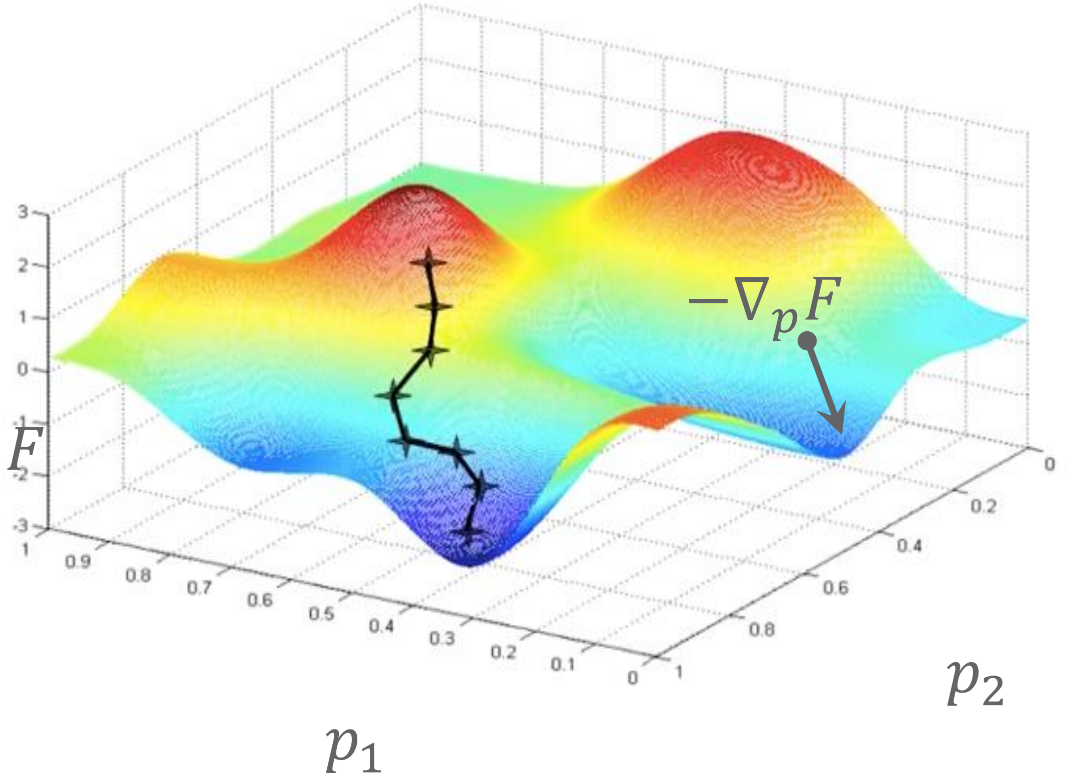
Parametric shape
- Defines design space
- Optimization parameters

Adjoint sensitivity analysis
- Efficiently compute gradient
- 2 FDTD simulations
- Independent of # parameters

Gradient based optimization
- Highly efficient optimization
- Uses more physics of device







https://hackernoon.com/gradient-descent-aynk-7cbe95a778da

Workshop outline

The challenge

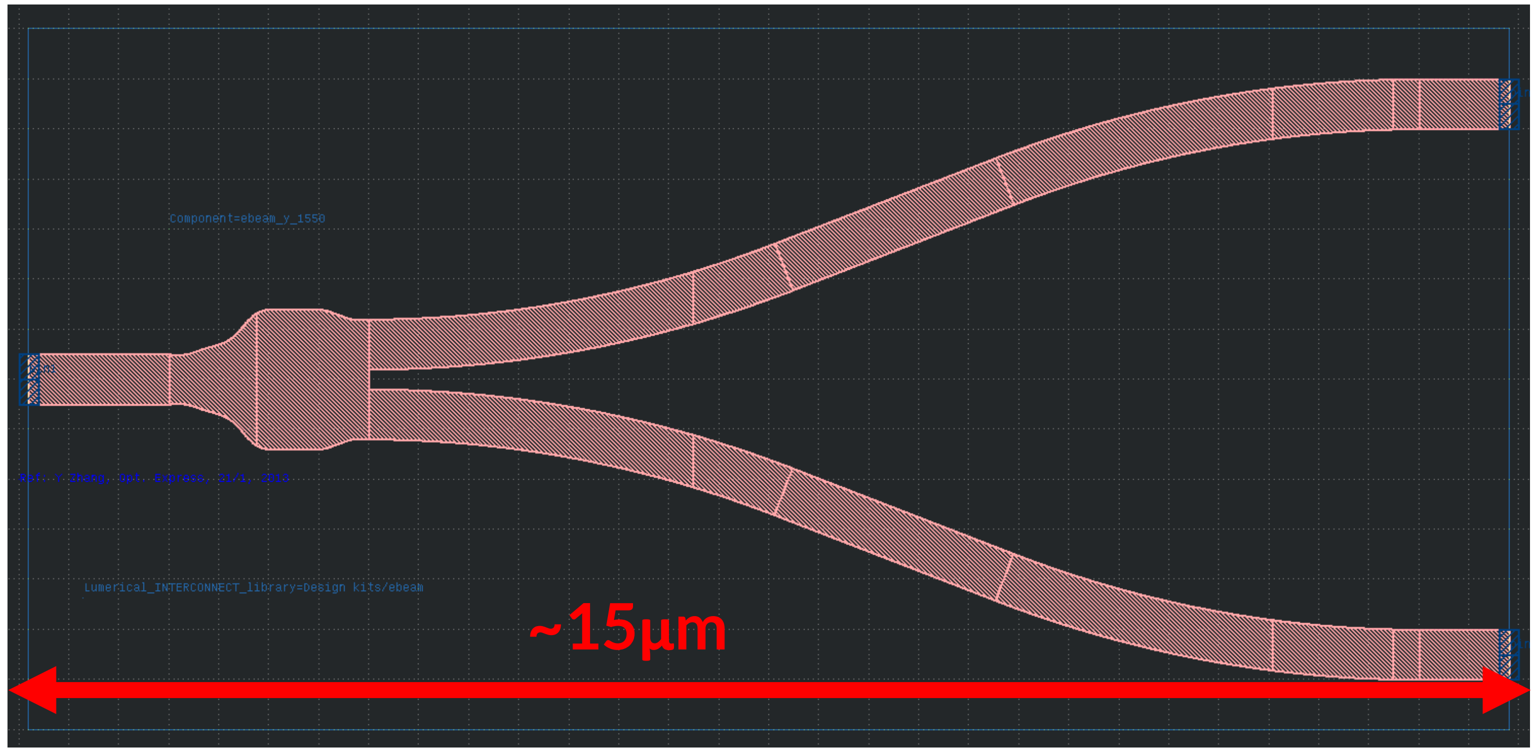
- Constraints
- Options you can change
- The figure of merit to determine the winner

Steps:

- Review constraints
- Make your design choices
- Start running optimization
- Generate 3D results and extract S parameters
- Generate full test layout by running Python script we’ve prepared with Klayout
- Inspect the full layout

The challenge

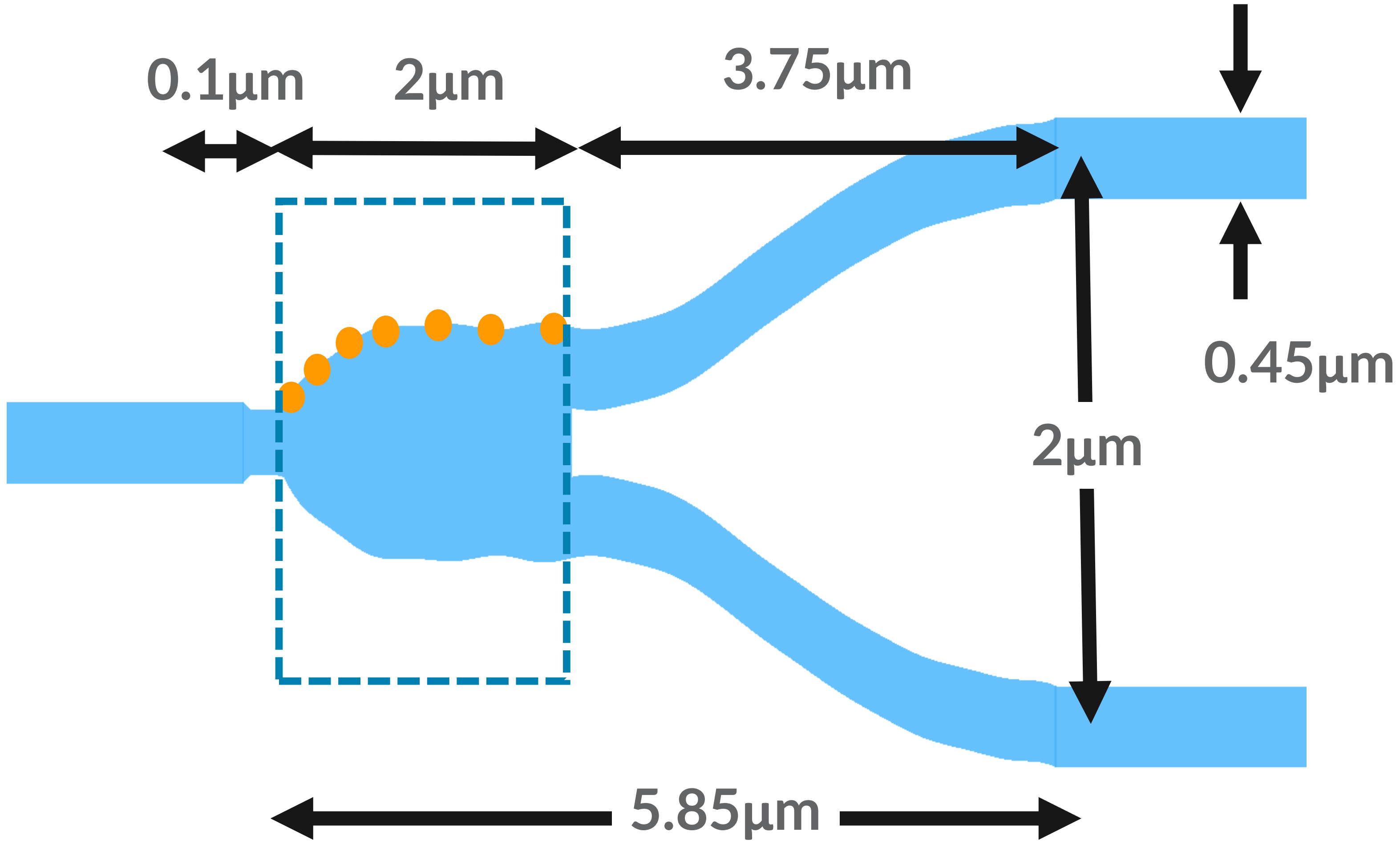
- Can we make a smaller splitter?
- Can we ensure broadband operation?



https://github.com/lukasc-ubc/SiEPIC_EBeam_PDK

A compact and low loss Y-junction for submicron silicon waveguide
Yi Zhang, et al, Optics Express Vol. 21, Issue 1, pp. 1310-1316 (2013)

- Parametric shape with output waveguides



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Design choices

Number of control points for the spline = number of optimization parameters

- Currently set to 10

Spline boundary condition

- ‘clamped’ or ‘not-a-knot’ – currently ‘clamped’ which means derivative is 0 at boundaries

Bandwidth

- Currently set to C+L band

Delta (for robust design)

- If delta==0 we do normal optimization
- If delta!=0 (see next slide)
- Currently delta = 20nm

Note that adjoint optimization is a steepest descent method

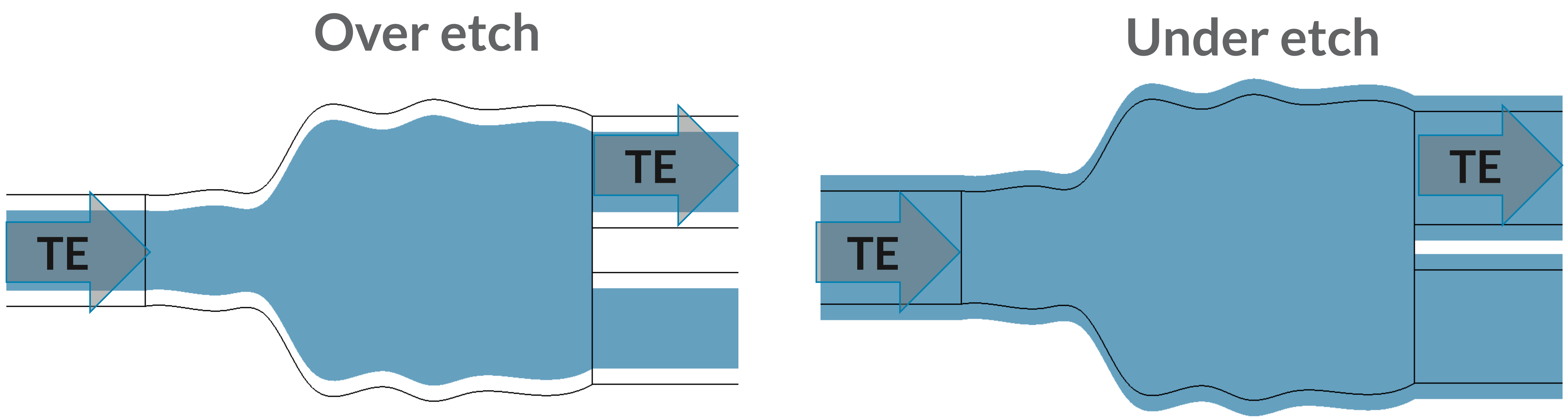
- Adding more constraints can actually smoothen the FOM landscape and allow you to avoid local minima BUT too many constraints will reduce the FOM

What does delta do?

If delta is not zero, we do co-optimization

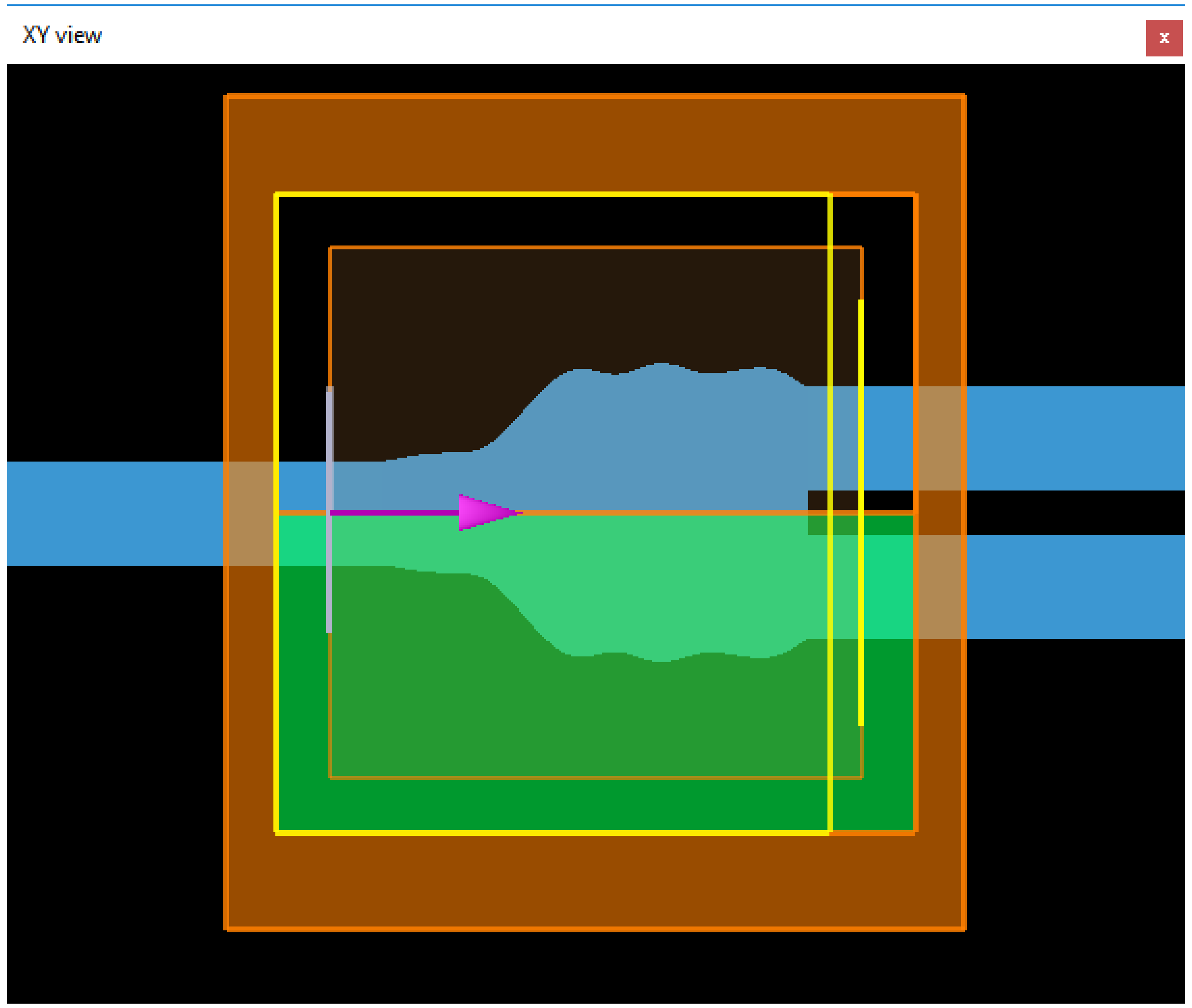
- “Over etch” slightly smaller than nominal (-delta)
- “Under etch” slightly larger than nominal (+delta)

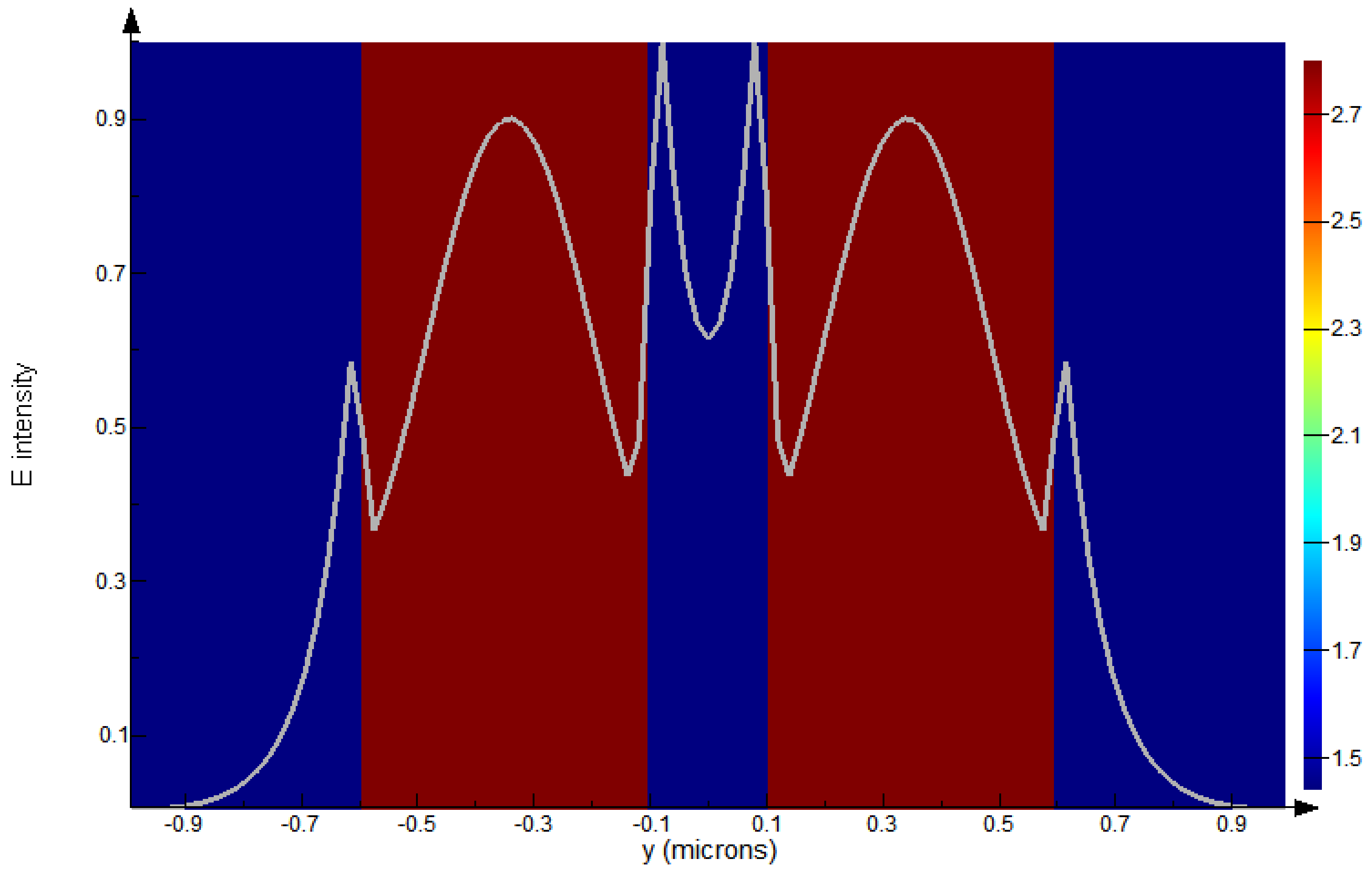
FOM = sum of FOMs from both simulations



What FOM are we optimizing?

FOM is the power transmitted to the symmetric waveguide mode



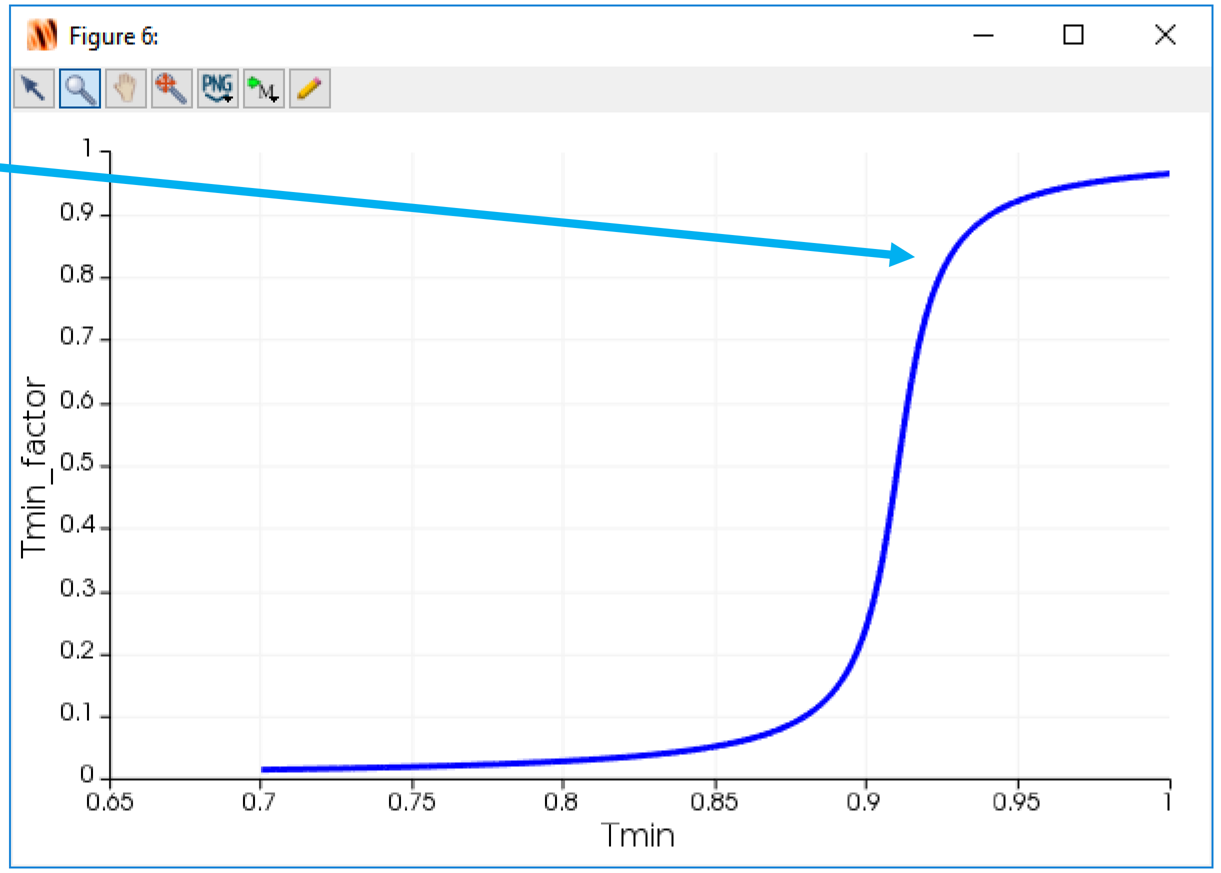


How do we judge the workshop winning design?

From 3D simulation including bent waveguide arms we extract the S matrix for the nominal design (no over-etch/under-etch)

The best design has the highest **design_score** where:

- **design_score = Tmin_factor * bandwidth_factor**
- **Tmin_factor = atan(100*(Tmin-0.91))/pi+0.5**
- **bandwidth_factor = bandwidth/100nm**
- **Tmin is the minimum transmission over the bandwidth**



There is a big cost to allowing your minimum transmission to fall below about 0.3 dB !

Running the examples in FDTD Solutions

Method 1: Easy

1. Open FDTD Solutions
2. Open .py file in FDTD script editor
3. Press run script

Uses Python and Lumopt provided with FDTD Solutions

Method 2: Power user

1. Install Python, SciPy, Jupyter
2. Configure Python path to Lumerical modules in <FDTD folder>/api/python
3. Open *.ipynb in Jupyter

Requires FDTD Solutions 2019a R6 (8.21.1933)
Software installer available on USB drive or web
Windows: http://lumeri.ca/zeqxy
MacOS: http://lumeri.ca/7d952

Windows

Mac

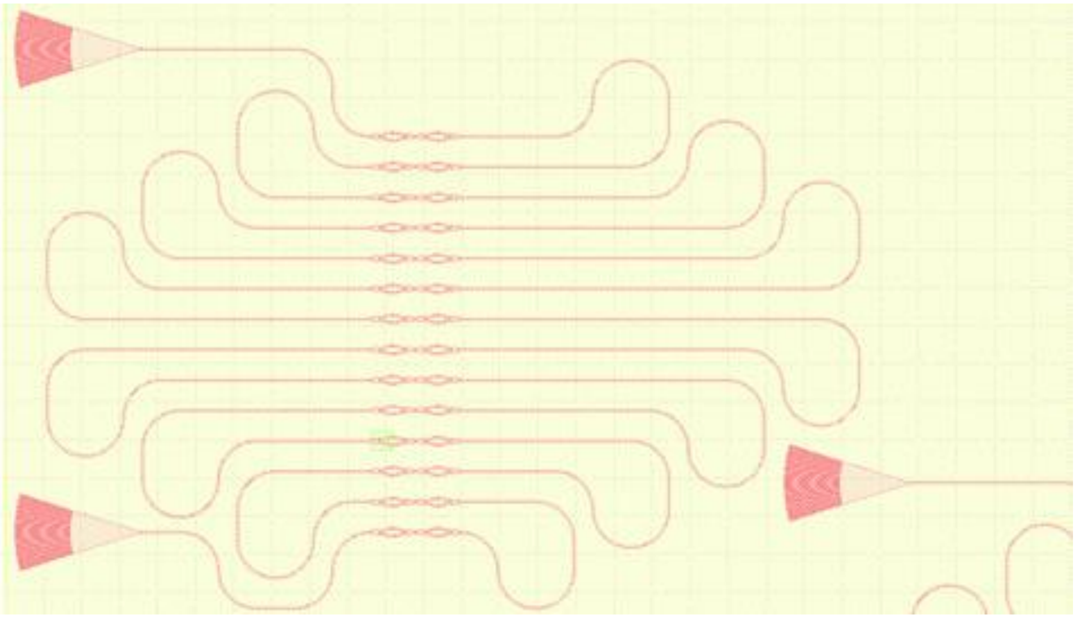
Making the full test layout

We provide a scripts called **make_test_layout.lsf** and **make_test_layout.py**

Run by

- Open **make_test_layout.lsf** and press run
    - You may need to edit the script depending on your Klayout installation folder
- Power users
    - Opening a command prompt and change to the directory where you are working
    - Run <KLayout install folder>\klayout_app.exe -r make_test_layout.py

Inspect with KLayout



Submit your design

See https://www.linkedin.com/pulse/openebl-fabrication-test-passive-silicon-photonic-lukas-chrostowski?trk=portfolio_article-card_title

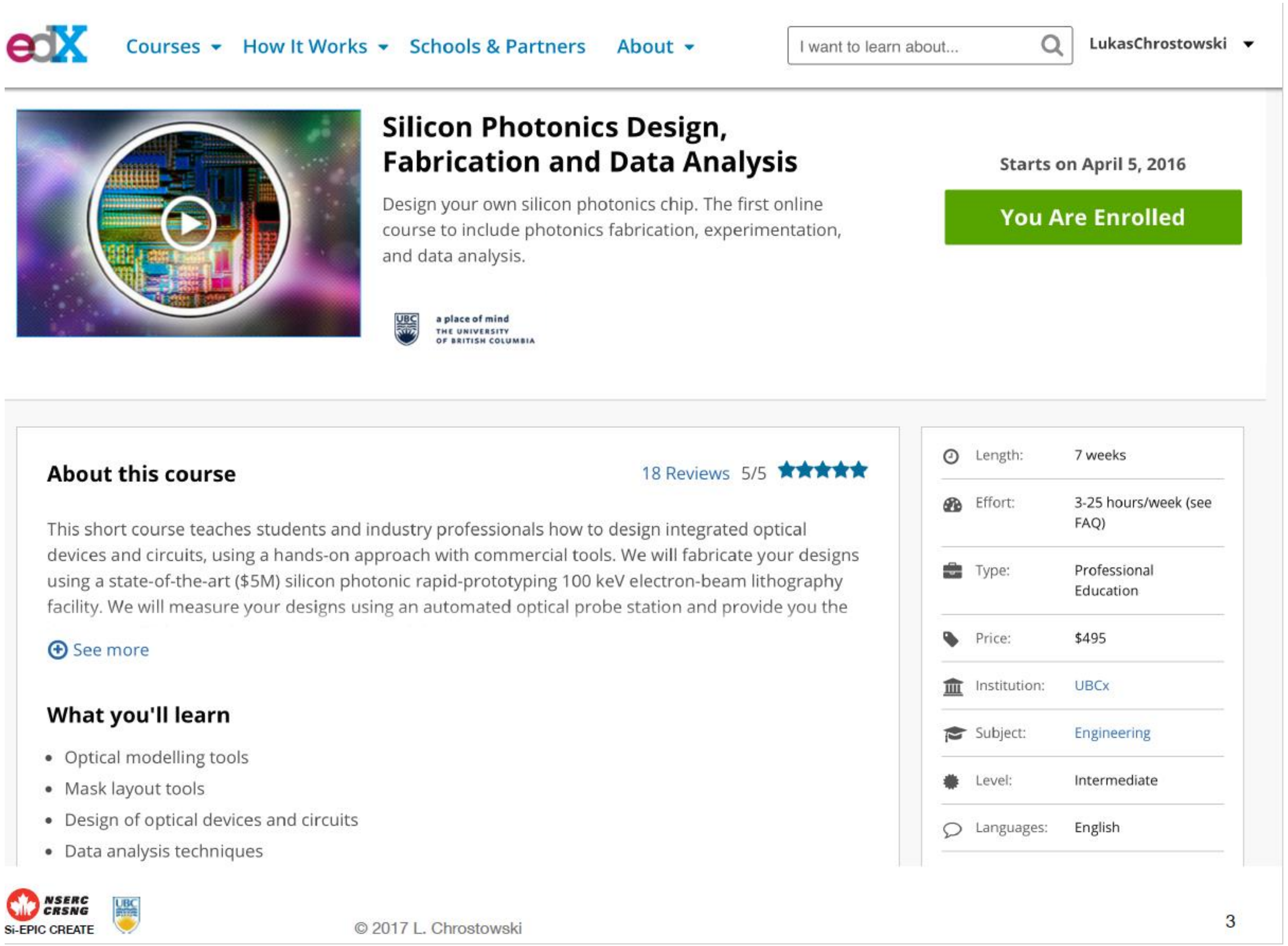
Key points

- Submission:
    - Filename – openEBL_USERNAME.gds – “openEBL” is case sensitive; replace USERNAME with your name. Append “_A”, “_B”, etc., if submitting multiple layouts.
    - Top cell – openEBL_USERNAME
    - Upload your GDS layout file here: https://bit.ly/2M4hPPTThe secret is the material that the waveguides are made of (hint: chemical element with atomic number 14)
- Merge verification
    - Download the following files, to check that your design is here and correct. There may be a 1-5 minute delay between submission and merge.
        - Merged GDS file: http://upload.siepic.ubc.ca/openEBL/openEBL.gds
        - Log file: http://upload.siepic.ubc.ca/openEBL/openEBL.txt
        - Automated measurement coordinate list: http://upload.siepic.ubc.ca/openEBL/openEBL_coords.txt
- Fabrication results:
    - Will be shared via Dropbox.com: http://bit.ly/1fiQe7I and https://www.dropbox.com/sh/030suvs0vk4pw66/AABDah85xHeMPgyARms73pCda?dl=0. To download a particular folder, replace the =0 with =1.

Disclaimer: Nothing is guaranteed. Provided as-is, best effort. The designs submitted here are publicly accessible. For educational purposes. Space limited; first-come first-served.

Next steps

Lukas Chrostowski's edX course!



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